THE JOURNAL OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

OCTOBER 1960

Vol. 54, No. 5 Whole No. 446

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

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SYMPOSIUM ON SPACE

This symposium was held at a joint meeting of Section III (Physical Sciences) of the Royal Society of Canada and the Canadian Association of Physicists, in Kingston, Ontario, June 8, 1960. It was planned to cover various aspects of space science under the chairmanship of Helen S. Hogg, Vice-President, Section III of the Royal Society of Canada and H. C. Duckworth, Vice-President, Canadian Association of Physicists, with the help of G. S. Field, Chief Scientist, Defence Research Board—Editors.

I. SPACE SCIENCE ORGANIZATIONS AND THE SCOPE OF PLANNED PROGRAMMES

By D. C. Rose*
National Research Council, Ottawa, Ontario

It is a pleasure to open this symposium on space science in Canada at a joint meeting of the Royal Society of Canada and the Canadian Association of Physicists. These are the two organizations which, if it can be done at all, should be able to look at space research with a true scientific objective at a time when the leading activities in this field are being supported because of a political rivalry that can hardly be said to be purely scientific.

The programme I am recommending for space research in Canada is small and mundane in comparison to the spectacular events published almost from day to day about the launching of larger and larger satellites with more and more complicated instrumentation. Nevertheless, small programmes can be very important.

Before explaining Canada's position in space, or rather what some of us feel our position should be, let us look at the whole picture. Historically the development of large rockets intended for offensive purposes has

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made an advance in science possible that was hardly dreamed of fifteen years ago. I do not mean by this that we should consider fabulous dreams of colonizing other planets or even of collecting a sample of material from the moon. It is simply that we know so little about the environment of the space surrounding the earth even at distances which are only one or two per cent. of the earth's radius above its surface. It is no exaggeration to say that the advance in technology which makes it possible to take direct measurements outside the earth's atmosphere will enhance scientific knowledge on just about as broad a scale as did the discovery of nuclear fission.

The intense rivalry between U.S.A. and U.S.S.R. in space activities is not entirely a bad thing. The development of satellite-launching rockets has gone far past the stage where each new one is considered as a weapon. In fact the larger satellite-launching vehicles would probably be quite useless as weapons. Even with our small capabilities in Canada the Defence Research Board has developed a rocket as part of a programme of propellant research which is giving great promise of being a very useful scientific vehicle and has no potential use as a weapon. The unnatural pace with which research, both in space vehicles and in space physics, is being carried out in the U.S.S.R. and U.S.A. must be sometimes embarrassing to scientists in those countries who would like to take time to do their experiments in a more logical sequence. It is doubtful, however, if public support would be forthcoming if a conservative logical sequence were tried. The point I wish to make is that once the vehicle has developed beyond the stage of a weapon and the desire for one-up-manship is in scientific or technological knowledge rather than destructively offensive, the ultimate outcome must have some good in it. This is so even if the logical step by step approach is forgotten in an attempt to be the first to get a close look at, shall we say, the beauties of Venus. To continue in this vein for another minute a great deal can be said in defence of the present objective of getting a man into space in a capsule containing extensive scientific equipment. A lot of the things we want to know about nearby space are rapidly varying physical quantities and direct measurement by a man who can use judgement is very desirable indeed. In spite of all that has been said about computing equipment and all the "if's" and "and's" it can handle, there is no way to build judgement into a machine until we know what is to be judged. I think the effort to get a man-carrying satellite in orbit above the atmosphere in a way that he and his equipment can be returned is not too illogical a step for those who have the capability to try.

Turning now to problems nearer home, there is no need for a small country to shy away from space research merely because it cannot com-

pete with the United States and the U.S.S.R. In fact there is a great deal for all to do and a lot of it is simply an extension of work in which Canadian science has already a leading position.

Until a few years ago our knowledge of the upper atmosphere (for the purpose of this talk take the upper atmosphere to start about the lowest levels of the ionosphere, say 50 km. and higher)—our knowledge of such regions was obtained by deduction from indirect measurement such as spectroscopy of the night sky and aurora or the reflection of radio waves from the ionosphere. We learned a great deal by such methods but got several surprises when rocket technology made direct measurements possible. For instance, the density of the gas above 100 kilometres was much higher than was expected and vague predictions that the temperature of the very tenuous gas at heights of several hundred kilometres was very high can now be examined directly. Space exploration in the upper atmosphere has opened up a new horizon in studying the sun, particularly the radiation and particles it emits. We now see that the earth moves in the solar atmosphere or that the sun's corona extends at least as far as the earth's orbit, and the interplanetary space outside our atmosphere is a very interesting place indeed. Even though it represents a vacuum, higher than can be obtained in the laboratory, it is full of gas and radiations on which very little thought had been put until recently when it became possible to measure them directly.

The earth's atmosphere is opaque to all radiations with quantum energies above about 4 electron volts, that is from the ultraviolet region up to higher energies. For a nuclear particle, an energy of about 2 billion electron volts (2×10^9) is required if it is to penetrate the atmosphere to sea level and no primary particle of any energy no matter how high penetrates the atmosphere without nuclear collisions which change its nature and create secondaries. Particles with energies up to one billion billion electron volts (10^{18}) have been detected. The region from ultraviolet light up to these large energies covers an enormous range and includes the complete ultraviolet, X-ray and cosmic ray spectra. Soft X-rays from the sun are found to be very variable and their study will improve knowledge of the storms on the sun's surface which are so interesting in understanding the evolution of this star. The solar atmosphere is very stormy indeed and the storms extend right out to the earth's orbit. The windy solar atmosphere interacts with the earth's magnetic field and direct measurements in the region where this takes place are making possible an understanding of the nature of the interaction.

In fact an attempt to use cosmic rays to study the symmetry of the earth's magnetic field at some distance from the surface led to the dis-

covery of the Van Allen radiation belts that surround the earth and that are of such great scientific interest.

In studying phenomena of this sort the measurements taken from one satellite produce a prodigious amount of data. Much of it is repetitive and, therefore, some of it is redundant. Its usefulness depends on either storage of information in the "bird" and releasing it on interrogation or by having many telemetering stations over the world. The former adds complications and the latter makes possible precise measurements of orbital perturbations as well as getting local physical conditions. This has important applications to geodesy. The Americans are far ahead of the Russians in getting scientific data from their satellites. They have stations scattered around the world and have arrangements with several other countries for tracking programmes. Tracking and analysis of data is one contribution that small countries in strategic positions can make.

Even though satellites are very useful they have their limitations in that they are not very practical in some of the very interesting regions of the upper atmosphere. The lowest practical satellite orbit, that is one with a reasonable life, is about 300 kilometres (200 miles). Starting from the earth upwards the highest practical level for airborne (that is balloon borne scientific instruments) is about 35 kilometres, say 20 miles.

The region in between 35 km. and 300 km. is the region to be explored by sounding rockets. It is also the most interesting from the upper atmosphere physicist's point of view. This region contains most of the aurora and the reflecting regions of the ionosphere. It includes the absorbing regions in the lower ionosphere, a study of which is so vital to radio communication. Most of these phenomena that are so interesting and important are caused by some form or other of interaction between the earth's magnetic fields and clouds of particles coming from the sun carried by so-called winds in the solar atmosphere. The temperature of these gases is very high and the particles are stripped of their electrons or ionized, making a highly conducting medium, that is, highly conducting in relation to the low density and large distances involved. It is this highly conducting stream that distorts and interacts with the earth's magnetic field.

This interaction is most prominent at high magnetic latitudes. That is it strikes down lower into the atmosphere at high latitudes and certain types of radio absorption and the aurora occur only in polar regions. The geomagnetic axis of the earth is tilted with respect to the earth's axis of rotation in a direction towards Canada and the only region in the world where accessible land stations cross the belt of maximum auroral activity

is in northern Canada. This picture is, of course, very qualitative and I know it is old stuff to many in this audience. It is reviewed here to emphasize the background, not only of a Canadian scientific interest in upper atmosphere research but of a certain Canadian responsibility in putting some effort into the field. Where our own efforts and capabilities in money and trained scientists are inadequate to meet the demand for world-wide knowledge of the atmosphere above northern Canada we can only welcome others in undertaking scientific research in our north and this is the situation that led to the building of a comprehensive rocket launching facility by the United States at Churchill, a site reachable by railroad right at the point of maximum auroral activity, and having already in existence the possibility of ground observation points studying the upper atmosphere further north such as Baker Lake and Resolute, and to the south the University of Saskatchewan at Saskatoon, Winnipeg and points in the United States. This is a situation for upper atmosphere research which is truly unique.

Traditionally, of course, Canadian scientists have met the challenge of these northern phenomena for some time. Work on auroral spectroscopy in Canada dates back to the early twenties. Inspired by the activities and the part played by Canadian scientists in the second international polar year (1932–1933) a school of auroral research has grown up in the University of Saskatchewan that has a world-wide reputation and in the post-war period has been enlarged by another group in this field at N.R.C. The technique of comprehensive ionosphere observation by the study of reflected radio waves was only developed during the depression thirties and came into its own after the war. The Defence Research Board's development of ionosphere research is now known everywhere among scientists having such interests. The N.R.C. cosmic ray group has taken measurements in the Arctic since 1949. This is a field where measurements in northern regions high up in the atmosphere are of particular importance because the atmosphere is completely opaque to cosmic rays of any type with energies below one or two billion electron volts and the only part of the earth where these can come in is in polar regions. This is because of deflections of the particles by the earth's magnetic field.

To recapitulate for a moment, I have pointed out that a very important region of the upper atmosphere is only accessible at present by modest sounding rockets—that is modest in relation to satellite-launching vehicles. The traditional interest of groups of Canadian scientists in this region has been discussed briefly and there is in existence a unique facility at Churchill. The most natural development for Canadian space research is to take advantage of our background of experience, our geo-

graphical position and the technical facilities now available: that is to develop a programme of research using sounding rockets to study the upper atmosphere over our northern regions.

This does not mean we should never look further afield. The experience of the Defence Research Laboratories in the ionosphere led to a suggestion for a satellite experiment known as a top side sounder which was so obviously sound that the United States gave it satellite space and I know from discussions at international meetings that all ionosphere research groups are looking forward to its success with some anticipation.

Other satellite experiments may be undertaken but for the most part we see the Canadian space research programme limited the way I have just mentioned to rocket probes into the northern upper atmosphere.

A year ago the National Research Council formed an Associate Committee on Space Research. One of the functions of that Committee is to co-ordinate space research activities so that university groups can take advantage of the opportunities offered. This activity is already bearing fruit. We expect to have two rockets launched in less than a year with experiments planned and the apparatus constructed at universities. There is no reason why this should not expand considerably if university research groups with experience and interest in the work that can be done by this upper atmosphere space probe produce their problems. The expense of this type of research is high but not prohibitive.

After the International Geophysical Year the International Council of Scientific Unions known as ICSU formed a special committee on space research. ICSU is formed from about fifteen international scientific unions representing various disciplines. The General Assembly of ICSU includes representatives from National Academies or National Research Councils as well as the Unions. Its special committees follow the same pattern and the Special Committee on Space Research has members from both International Unions and National Academies or National Research Councils. The title of this Committee is abbreviated to COSPAR. Both ICSU and its special committees, since the membership is not directly from governments, are supposed to be non-political in nature and COSPAR tends to avoid any part of space science that might be closely associated with weapons, that is, it omits from its terms of reference anything to do with propulsion or guidance of rockets or satellites. COSPAR got off to a good start nearly two years ago but the selection of representatives accidentally, I am sure, left a disproportionately low number on the side of the iron curtain countries and politics crept into its organization. It took about a year to resolve this but now it appears again likely to be successful. Canada being a rocket launching

country, the National Research Council holds a membership seat on COSPAR.

The United Nations at its 13th General Assembly also formed a Committee on the Peaceful Uses of Outer Space. Since the United Nations is a political organization, politics is naturally likely to take precedence over scientific objectives. The first committee formed by the 13th General Assembly consisted of 18 nations but there was never agreement on its composition and five of these nations boycotted the Committee. Nevertheless it met and produced a report in spite of the boycott. The report was non-political in nature, very informative and contained some substance in that it recommended a very modest U.N. space activity. The report was quite well received and a second committee was formed by the 14th General Assembly just last January. This committee has a membership of twenty-four nations again including Canada. Up to the present this committee has not met and one reads of behind-the-scenes bickering on agenda and officers. The resolution forming the committee, also instructed it to organize an international conference on the Peaceful Uses of Outer Space. We hope this will be held soon.

In this discourse I have omitted several important aspects of space activities. Biological scientists have a considerable interest not only for medical reasons but because the possibility of different types of biological organisms on other planets is fascinating and the horrible consequences that might develop from mixing them with ours must not be overlooked. Much also has been written on the legal side and one can foresee years of very serious argument and negotiations over sovereign rights of the space above us.

II. THE FRINGE OF SPACE

By W. Petrie*
Defence Research Board, Ottawa, Ontario

Introduction. By the fringe of space I am referring to the outer part of the earth's atmosphere. Although this region is very tenuous indeed compared with the air near the earth's surface, it does have a profound effect on a phenomenon called an atmospheric disturbance. The development of a full understanding of the nature of this disturbance is one of the challenging problems facing physicists. In addition a number of experiments now under way and others in the planning stage are aimed at the exploration of space beyond the vicinity of the earth and it is desirable that we have reasonably complete knowledge of our immediate surroundings since this information may affect planned experiments. For these reasons, a good deal of effort has been expended on an exploration of our upper air.

Until 1958 one might have considered the fringe of space to be at a height of some 400 miles. That is, the air above this height would have little effect on events recorded at the earth's surface. However, a very dramatic discovery in that year, which I will describe later, has made it clear that the atmosphere out to the great distance of perhaps 40,000 miles must be considered in order to understand certain phenomena.

Ground Based Studies of the Atmosphere. Now that we have defined the region of interest in terms of distance from the earth's surface, I will say something of the equipment which is used to study our planet's outer atmosphere. Until quite recently it has been necessary to make measurements from the ground or from aircraft. The principal methods of investigation include radio studies of electrical charges in the high atmosphere, radar studies of the aurora and meteors, an examination of the aurora and night sky with optical devices, an analysis of changes in the earth's magnetic field and the recording by radio telescopes of radio waves from space. I will say a few words about a number of these methods.

Radio studies have yielded an astonishing amount of information on the electrical state of our upper air. It is now known that there are four main layers containing electrically charged particles and the state of these layers at any one time determines whether radio communication will be favourable or unfavourable.

Radar energy can be reflected from the northern lights and tell a good deal about the physical state of that phenomenon. Also, by using

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radar to look at the electrically charged trail which is formed by the passage of a "shooting star" one can learn something of conditions in the air through which the meteor passes.

The upper atmosphere always emits a certain amount of radiation, giving about as much illumination as a candle at a distance of 300 ft., and at times becomes very much "lit up" by producing the aurora, which is comparable in brightness to that of the full moon. Both the steady radiation from the atmosphere and the transitory variety from the aurora may be examined by spectrographs and information obtained on the temperature and composition of the upper air.

It was observed in the year 1931 that radio waves reach the earth from a source in space. The subject of radio astronomy is now an extensive one and astronomers use large radio telescopes to study emissions from various parts of the universe. As these radio waves pass through the earth's atmosphere they fluctuate depending upon the conditions encountered, and a study of the fluctuations tells a good deal about what is going on in the upper atmosphere.

These various activities have yielded much information on the properties of the atmosphere and have contributed to an understanding of the relationship between the sun and events which take place in the upper air, such as the aurora. However, the atmosphere "gobbles up" much of the information which could be available to us and earth-based equipment only records a residue. In order to utilize the information which is available if one can reach sufficiently high, an increasing effort is being devoted to sending instruments aloft in balloons, rockets and satellites.

Studies From Vehicles High in the Atmosphere. The balloon is a relatively steady vehicle and hence has advantages as a platform for observations, but it will only reach to a height of some 25 miles. The rocket can be sent to great heights, but the device passes through the region of interest in a few minutes, thus only allowing relatively few data to be collected. For observations of events which last hours or days the artificial satellite is the desirable vehicle.

The most important reason for reaching to the top of the atmosphere is to study the nature of the radiation and particles which are directed at us from the sun and from other astronomical bodies. In particular, much attention is being directed to an examination of atmospheric disturbances to which I have already referred. By such a disturbance is meant the conditions which exist when the sun "spews" out an excess of radiation and particles which in part impinge on our outer atmosphere. The manifestations of a disturbance are the appearance on the sun of certain features followed by changes in the earth's ionosphere, the magnetic field of the earth, the appearance of auroral display and other effects.

The most striking discovery which has resulted from the use of satellites was the detection in 1958 of two extensive belts of electrically charged particles which surround a good portion of the earth. The majority of the particles in these belts originate in the sun and as they encounter the outer part of the earth's magnetic field become "trapped" and remain in this condition on the average for a considerable period of time. The shells of particles which are formed result from two motions, one a spiralling motion along a magnetic line of force from north to south and back again, the other a drift around the earth in either an east or west direction. The north-south motion is completed in a few seconds, the drift around the earth in a period of some 40 minutes. Puck's boast in *A Midsummer Night's Dream* that "I'll put a girdle round the earth in forty minutes" is thus prophetic.

Evidence is accumulating from satellite-recorded data that the Van Allen particle belts play an important part in the development of an atmospheric disturbance. The outer belt at least apparently discharges its particle population under the influence of bombardment by material from the sun. The ejected particles in passing downward towards the earth's surface likely generate, at least in part, several events which are observed during a disturbance. A substantial effort is planned to make the measurements from satellites which will allow a more complete understanding of the events occurring at the top of our atmosphere.

Those who are interested in sending men into space are concerned with other aspects of the particle belts. The level of radiation at times may be such that traversal of the belts will produce a hazard to man. More data are required before conclusive statements can be made on this subject.

In concluding, I would like to point out that in this field of upper atmospheric studies, certain theories have been based on fragmentary observational evidence. It was said of the philosopher Herbert Spencer, that his idea of a tragedy was a theory killed by fact. We must be prepared for the demise of much theory as space vehicles fill in the gaps in observational data and undoubtedly there will be surprises ahead.

III. BIOSCIENCES RESEARCH AND SPACE PROBLEMS*

By M. G. Whillans†
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Introduction. The purpose in this brief presentation is to highlight a few of the more important problems facing those who plan to put man into space, and to indicate how investigations in the biosciences related to space problems may assist us towards a better understanding of life and of ourselves. The "biosciences" embrace all scientific disciplines bearing on life and living processes.

The role of biosciences in space exploration has so far been a modest one, and this is as it should be. To many of us, it seems that a larger part for future biosciences work should follow the acquisition of larger rocket payloads, improved reliability of engines and guidance systems, and more precise knowledge of the environment of space. Every improvement in these is a gain towards any man-in-space programme. The United States commitment in project "Mercury" has resulted in a sharpened perception of the problems to be overcome in achieving the first objectives. Planning has been more definite, money and special abilities have become available for studies of the most thorough-going character, and a new, closer teamwork between the engineers and bioscientists has already been achieved. It is also probable that basic research in several areas will derive an added boost from this project.

We in Canada for some time have had a number of studies underway having a direct application to space problems, but our effort is relatively small, and can be justified on its application to problems of flight in the atmosphere.

Man may have to go into space, if only to pioneer the way for his machines or "mechanical slaves". He may have to make some direct studies to obtain a more satisfactory remote control of these slaves, and the development of better mechanical survey and collecting facilities. Putting a man into space and recovering him safely is mainly an engineering problem. The information is available now to enable this to be done. Human tolerances to acceleration and deceleration are not excessively restrictive (they are, in fact, surprisingly generous), so that blast-off and re-entry procedures should be exclusively engineering problems.

*Summary of address

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Rescue from space presents another order of difficulties, but even here the experts say that it is possible.

Disorientation and Zero Gravity. Disorientation may prove a most difficult problem. If artificial gravity is induced by rotation of a space vehicle there may be alarming disturbances in the sense of position. Movement of the head during angular accelerations produces marked and immediate disorientation. While a reasonably satisfactory degree of adaptation to increased gravitational forces and to a rotating environment can be achieved, we have so far had difficulty with fields of varying g forces and angular accelerations. If some artificial gravity is not provided there may be less disorientation, but it may be difficult to ensure adequate stability of the space vehicle. Also, we cannot yet say that prolonged exposure to a zero gravity environment will be harmless.

A great deal of the much-publicized work on zero gravity effects is practically worthless. The 30 seconds or so of zero gravity so far experienced, can be achieved only by flying a high-speed aircraft along a Keplerian trajectory, *immediately after* periods of two or more "g's". It is difficult to ascribe any physiological changes to zero gravity, when the subject must still be recovering from this prior exposure to increased g forces.

There was a good deal of speculation, three or four years ago, as to whether urination was going to prove difficult in the weightless state. A few subjects had unsuccessfully attempted this simple act during a 25–30 second period of zero-g, and their reports created fears that this would be a worrisome problem. Was this inability due to lack of stimulation of the floor of the bladder (trigone) from the weight of urine? A brief search into history provided some reassurance. In the seventeenth century a practical test for stone in the bladder had been employed. If the patient could pass urine while standing on his head, but not when standing upright, he was said to have a stone. So the bladder's response does not altogether depend on gravity. Recent successful tests, in any event, have removed this worry!

Although conclusive studies remain to be done, it seems that our gravity sense receptors are not vitally necessary. Removal of the organs of balance does lead to difficulties, but visual references are soon established, as studies on turtles and cats have shown. Clinical experience shows that people who have lost the function of both inner ears make satisfactory adjustments and are relatively immune to disorientation from accelerations. In short, if the astronaut can be trained to ignore or adapt to messages from his organs of balance he should satisfactorily orient himself in the zero gravity state by means of his vision.

Gravity can play an important role in determining the growth and perhaps even the morphology of animals and plants. Higher than normal gravitational forces have not interfered critically with the growth and reproduction of laboratory animals. However, root and stem growth patterns of plants can be seriously disorganized if there is no consistent gravitational force acting on them, as I have proven to my own satisfaction in some studies of my own. The study of auxin shifts in plants in relation to the direction and force of gravity should prove rewarding.

Radiation. We do not yet know enough about the radiation environment of space to plan lengthy trips beyond the earth's atmosphere. The strengths of the radiation fields in the Van Allen belts are impressive. Although exposure levels in the inner zone of the Van Allen radiations are roughly 10 r./hr. as compared with many times that level in the outer zone, it is the inner zone which is far more dangerous. The energies in this inner belt are such that up to 40 gm./cm.^{2} of lead shielding or equivalent would be necessary to protect a man from damage.

Intense solar flares may prove the greatest single threat for interplanetary flights. How the space traveller may avoid exposure to these is not known. An impractical amount of shielding for the larger flares would be necessary if undue risks were to be avoided.

Isolation. The possible hazards of isolation have aroused a great deal of interest and speculation. Hebb's series of studies on the effects of isolation on normal humans demonstrated in a dramatic way how serious this problem may be. Bizarre hallucinations may occur, and irrational ideas may be entertained by some subjects. This aspect of human behaviour requires more study, and other workers are investigating it here in Canada and elsewhere.

When greater rocket thrusts have been provided to afford adequate living room in the space vehicle, permitting some companionship, recreation and changes in routine, these difficulties will no doubt prove less troublesome or non-existent.

Food and Oxygen. Probably much more time has been spent in writing and talking about closed ecological systems for space travellers than in working on the problems. Most of us are familiar with the concept of the closed ecological system whereby oxygen is regenerated from carbon dioxide through the use of algae and photosynthesis. The algae would live on a synthetic substrate fortified with excreta. The result is that the oxygen in the cabin atmosphere would be maintained at satisfactory levels and the excess algae could be processed to supply food for the astronaut. Even the most enthusiastic advocates of this approach have

been far more cautious lately about promising that a satisfactory system will soon be available. Small leaks in the apparatus can add up to serious losses in a few days, there are the many problems in keeping any culture of this type in a healthy condition, and free of toxic products. So far no one has formulated a palatable soup or solid food from the algae. Efficient as biological systems may be in photosynthetic gas exchanges, they may not be as satisfactory as a chemical regeneration system. For example, the Sabatier reaction, involving the recovery of oxygen and water from CO_2 and H_2 (the H_2 derived from the electrolysis of water), may provide a superior method of supplying oxygen with the least on-board weight, for voyages of 3–8 years duration.

Basic Research. The exploration of space will not only widen our horizons, it should also help us to look more deeply into our own mysteries on earth. It has already stimulated much discussion on the origin of life. Now that we are aware that there may be an opportunity before long to explore the moon and other planets, the familiar questions have become more insistent. What forms of life may exist on other planets? How did the earth's rich variety of life forms begin? Is life being created now, *de novo*, here on earth or on the planets? Could a form of life exist which is based on some other than the carbon atom? Are nucleic acid derivatives necessarily the basic ingredients of life? I shall merely take note of the increasing appreciation of Haldane's work in 1928 on the formation of amino acids from simple inorganic molecules under strong ultraviolet light, of Oparin's theories as given in his book on *The Origins of Life* which some claim to be at least equal in importance to Darwin's *The Origin of Species*, and of Sidney Fox's feat in producing cell-like bodies from long-chain polypeptides. Khorana's recent synthesis of coenzyme A, the 'dissection' and 'reassembly' of the tobacco mosaic virus, and the characterization of the DNA molecule are impressive examples of progress towards biogenesis in the laboratory.

If life exists on Mars, what forms could it take? Martian conditions have been simulated in laboratories as closely as possible, and under these conditions a number of hardy micro-organisms have survived and multiplied. So we must admit that life could exist on Mars.

An increased interest in biological rhythms has been evident lately, and this again may be due in part to the advent of the space age. We know that the human organism does not rapidly adjust to changes in day-night cycles, and that a change to an 18-hour or a 30-hour simulated day would lead to significant losses in efficiency and well-being. Given enough time, we can "reset" our biochronometers, and experience and studies on animals and humans have confirmed this, but there are

definite upper and lower limits beyond which even adaptive mechanisms will fail. More information on the effects on health and efficiency of changes in diurnal rhythm is needed, not only for space travel purposes but also for various earth-bound situations.

Speaking of time schedules leads to a natural question regarding the possible reality of the time dilation-contraction phenomenon in space travel (the 'Clock Paradox'). I am leaving this question for others who are more familiar with the theory of relativity.

Navigation through space can pose many difficult problems, and it is significant that the engineers and physicists are turning to the biologists for clues. How is it possible for a blind homing pigeon to find its way home? By what mechanism does the eel navigate across the Atlantic and back without obvious navigational assistance? How do newts, even when blinded, unerringly retrace their way upstream to their particular birthplaces? There are indications from Italian studies that the homing pigeon, for example, has some amplification system in that part of its central nervous system which responds to angular accelerations. The action potentials recorded in brain stems of these pigeons are much more pronounced following slight accelerations than are these responses in other domestic pigeons. If the response is to geodetic forces, this implies an almost unbelievable sensitivity in the pigeon. If geomagnetic lines of force provide guidance, we shall have to look further for an explanation, as suitable receptors have not been found in the pigeon's body. More effort to explain this phenomenon is clearly indicated.

How can we talk rationally about trips to other solar systems when years of travelling may be involved? The ready answer is that we should put the crew into a state of hibernation or "deep freeze", and wake them up or thaw them out in time for the observation or landing at destination. The newspapers have seized on this, and have given prominence to the prospect of travelling through space in the hibernating or frozen state. Before we dismiss this possibility as both fantastic and unattractive, we should remind ourselves of the great advances which have been made in the clinical use of hypothermia during the last fifteen years. Also, it is said on good authority that bats may survive cold winters, apparently through supercooling. If bats can safely supercool, why not other mammals? We should encourage studies along these lines. Such studies are bound to lead to a greater understanding of cellular metabolism, improved treatment for many diseases, and important surgical advances. Other solutions may have immediate applications toward improving the comfort and efficiency of our earthbound daily lives.

It may be the search, rather than the ultimate goal, which will provide the greatest reward from the study of space problems.

IV. SPACE ASTRONOMY

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It is necessary to define what we mean by "space astronomy". Astronomy is the scientific study of the heavenly bodies. Since, in the past, man has been restricted to observations from or near the surface of the earth, astronomy has of necessity involved the study of the heavenly bodies from a distance. In view of the above it is proposed to define space astronomy as the scientific study of the heavenly bodies by observations made in space, and at a distance from these bodies. On this basis automatic moon photography from our satellite's far side, such as recently achieved by the scientists of the U.S.S.R., would properly come under the heading of space astronomy; while the collection of soil samples from the lunar surface would not.

Ground-based astronomical observations have been possible because of the arrival at the earth of electromagnetic radiation, particles of atomic dimensions, and larger particles of dust or meteoretic material. For astronomical studies the radiation is by far the most important.

The basic instrument of the astronomer is the telescope. Its function is to collect and concentrate radiation from a wide beam and thus intensify the observed image, while at the same time providing resolving power which makes possible the detection of fine detail. In general the larger the telescope the more radiation collected and the more detail revealed. Also, the longer the wave-length used the larger the equipment necessary to achieve comparable results. At present the world's largest optical telescope has a diameter of just under 17 ft. while the largest radio telescope collects radiation from a beam 250 ft. across.

In its initial stages the chief difference between space astronomy and other more conventional methods of astronomical research will be the ability of the astronomer to transport his telescopes into space. This will make possible certain types of observation, previously impossible with instruments located on the earth's surface. For example, the earth-bound astronomer is restricted to observing the universe imperfectly through two atmospheric "windows" in the electromagnetic spectrum; the optical, between wave-lengths 0.3 and 13.5 microns, and the radio, between wave-lengths 2.5 and 2000 cm. It is necessary to examine in detail the environmental changes resulting from mounting a telescope on a space platform. These can be grouped under four main headings:

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(1) *a condition of no-gravity, or very little gravity in comparison to the earth's surface*
  (a)—no appreciable weight for instrumental components,
  (b)—solids and liquids have positional instability,
  (c)—the telescope base requires stabilization of some form;
(2) *no limitation of position of telescope to surface of earth*
  (a)—freedom to choose the orbit of the instrument,
  (b)—possibility of a base established on a natural planet or satellite;
(3) *a condition of no air occuring naturally around the telescope*
  (a)—instrument must be operated by remote automatic control, or the support of life of any operator must be organized,
  (b)—no wind or atmospheric weathering of equipment,
  (c)—problems of electrical insulation must be reconsidered;
(4) *no terrestrial atmosphere between telescope and object being observed*
  (a)—no local absorption of certain wave-length ranges,
  (b)—no limitations to resolving power imposed by atmospheric conditions,
  (c)—no interference resulting from atmospheric luminosity of various types,
  (d)—no screening from the high energy radiations and meteoritic dust of space.

The above points indicate both the advantages and disadvantages of operating a telescope in space. The reduction in effective weight will solve many problems of distortion resulting from the flexure of components in large instruments. On the other hand weightlessness introduces its own problems, both mechanical and physiological. The maintenance of a living operator in space is beset with more difficulties than most people realize. The space astronomer must be prepared to utilize to the fullest extent the latest developments in automation and remote control. Undoubtedly the biggest dividend resulting from the operation of a space telescope is the extension of the observable range of wave-lengths into the complete ultraviolet and infrared spectrum, and the elimination of the disturbances produced by the earth's atmosphere. Once large space telescopes are established a completely new realm of astronomical research will be available. Yet here again we must be prepared for adverse conditions. No one yet knows how serious will be the pitting of optical surfaces by the fast flying space dust.

Already we have seen the beginnings of space astronomy. Since 1946 Tousey and his co-workers have made use of rockets to transport solar UV-spectrographs above the major part of the earth's atmosphere (Tousey 1953; Friedman 1959). This has resulted in a detailed study of the sun's spectrum down to a wave-length of 500 A. A start has also been

made at surveying the sun's surface and the entire celestial sphere at wave-lengths in the 1200–1400 A. range.

Recent work by Sinton (1959) on the infrared spectrum of Mars has produced some of the best evidence available to date for the existence of non-terrestrial organic molecules. This type of research gives promise of further advances in our knowledge of the planets when the complete range of wave-lengths in their spectra is available for study.

The outstanding achievement in space astronomy up to the present is the photography of the far side of the moon with automatic-cameras carried in the Russian satellite Lunik III (Nesmeyanov 1959; Barabashov and Lipskii 1959). It is probable that for some time to come astronomical results secured with remotely controlled equipment will be more important than any direct observations by possible future space travellers.

To place large telescopes in space will require a considerable advance in rocket power over what is now available. Figure 1 illustrates the

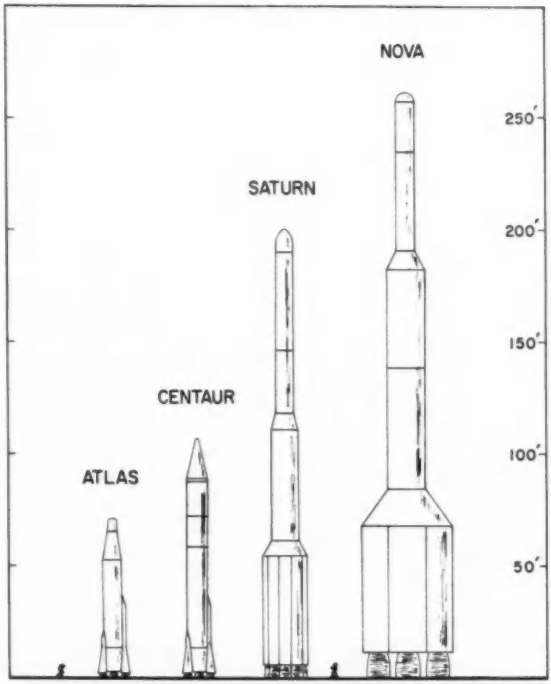

FIG. 1—Proposed space rocket developments in the 1960–1970 period, as announced in the U.S.A.

proposed rocket development in the U.S.A. over the next 8 or 10 years. This is based on the programme announced by NASA, the National Aeronautics and Space Administration. The Atlas is available now, and is capable of placing over 7000 lbs. in a satellite orbit near the earth, or 700 lbs. on the moon (Newell 1959). The Nova, with a six million pound thrust, will make possible 20 to 30 times these pay loads.

Several specific suggestions concerning space telescopes have been advanced. As examples the following can be noted:

A solar X-ray spectrograph with an over-all weight of 300 lbs. This has been designed for photographing the solar spectrum in the 1–100 A. region (Townsend 1959).

An 8-inch telescope for a four-colour survey of the entire sky in the 1000–3000 A. range; angular resolution 1 minute of arc (Davis, McCrosky, Whipple, and Whitney 1959).

A 24-inch telescope, proposed by Lyman Spitzer, Jr., Princeton Observatory, over-all weight about 2000 lbs. For suggested arrangement of equipment in satellite see figure 2. This instrument would have a guiding accuracy of 0.1 second of arc over a 12-hour period, and would be used for the photography of stellar spectra in the 800–3200 A. range (Melin 1960).

A 50-inch telescope, proposed by Aden B. Meinel, Kitt Peak Observatory, over-all weight 5000 lbs. (Federer 1960). Two pairs of guiding telescopes will lock on bright stars to maintain orientation in space as indicated in figure 3. This instrument is planned for a 24-hour orbit which will make possible continuous control from one ground station. A large range of observing programmes is possible with such a telescope.

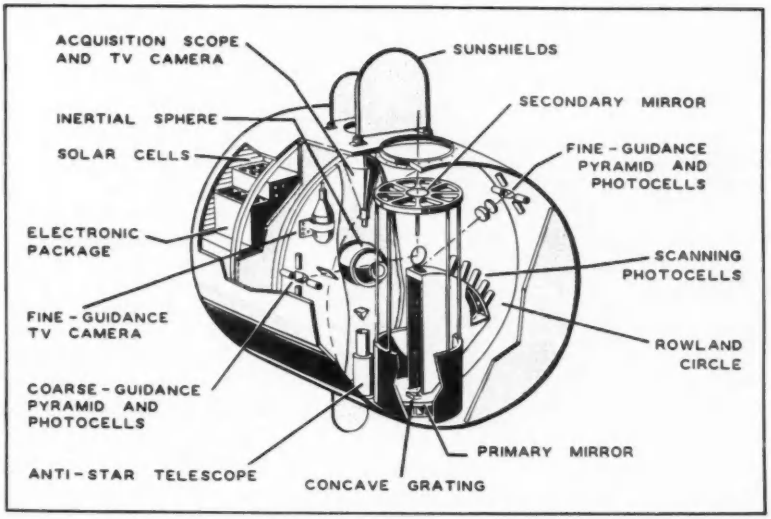

FIG. 2—Satellite carrying a 24-inch UV-telescope as proposed by Lyman Spitzer, Jr., Princeton Observatory. (Illustration courtesy *Sky and Telescope*.)

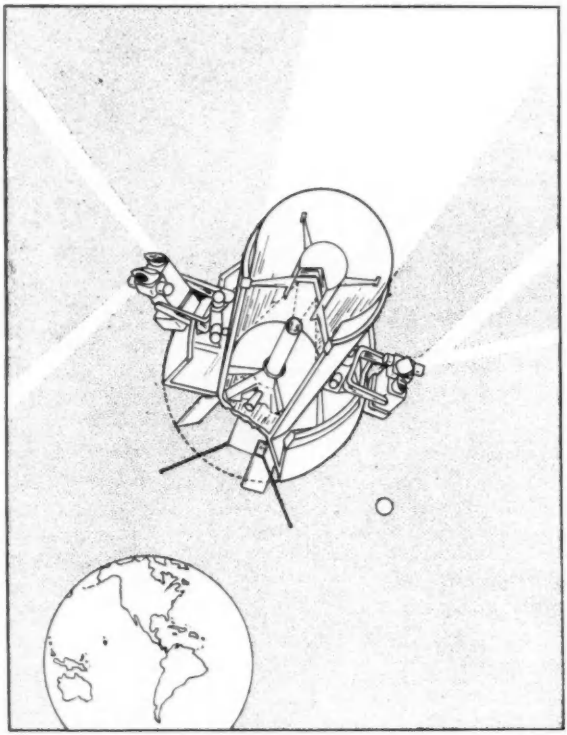

FIG. 3—The proposed 50-inch space telescope on the programme of the Kitt Peak Observatory. The earth and moon are shown to scale as they would appear from a 24-hour orbit. (Illustration adapted from Kitt Peak Observatory drawing.)

As space technology advances the scope of space astronomy is almost limitless. At first it is likely that the major area of concentration will be in the short wave-length region of the spectrum. This will be due both to the importance of this range in fundamental atomic studies, and to the fact that UV-instruments are somewhat smaller and less massive than those designed for the study of longer wave-lengths.

It must be remembered, however, that the new field of radio astronomy has shown promise of extending our space horizons to a greater distance than is possible with optical observations alone. To achieve high resolving power in the radio wave-lengths will require immense equipment, and it is obvious that the assembly and operation of such equipment will be more practical well away from the earth's gravitational force. In the

long run it is quite possible that space radio astronomy will make the most startling contributions to our understanding of the universe.

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THE ANTIQUITY AND PRECISION OF MAYAN ASTRONOMY

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This paper will present evidence that Mayan astronomy had its origin in the distant past and that by the fourth century A.D., the Mayans had a surprisingly accurate knowledge of certain areas of astronomy. A new correlation of the Mayan and Christian calendars will be offered, along with some arguments in support of it.

The Mayans had a calendar in which each day was given a number indicating its position in a continuous count of days from a zero date in the distant past. Such a "long count" is now usually designated by five integers, say 9–9–16–0–0, which means 9 baktuns of 144,000 days plus 9 katuns of 7,200 days plus 16 tuns of 360 days plus zero uinals of 20 days plus zero kins (or days). In other words, 9–9–16–0–0 corresponds to 1,366,560 days in our decimal notation. If A be the Julian Day Number of the zero date of the Mayan calendar, then $A+1{,}366{,}560$ will be the Julian Day Number of the date, 9–9–16–0–0, and from it, one can easily determine the date in the Julian or Gregorian calendar. Some fifteen or twenty correlations between the Mayan calendar and the Julian Day Count have been offered to date, and each of them may be specified by a value of A.

The Mayans often used a day number and a day name, plus a month number and a month name to indicate a date. The day numbers ran from 1 to 13 in order and then repeated. The twenty day names were used in order in a similar repetitive pattern. There were eighteen months of twenty days each, the days being numbered in order zero to nineteen, and one month of five days numbered zero to four. The month number combined with a month name thus placed a date within a 365-day year, while the day number and the day name placed it in a 260-day cycle. After an interval of 52 years of 365 days, the same combination of day number and name, and month number and name would occur again. It is clear then, why the long count was needed to avoid ambiguity for intervals longer than 52 years.

The interval of time between the zero date of the Mayan calendar and the initial date of the Venus ephemeris in the Dresden Codex (pages 24, 46–50) is the long count of the latter date, 9–9–9–16–0, or 1,364,360 days. This is a close approximation to $3735\frac{1}{2}$ tropical years; dropping 183 days for the half-year, and dividing by 3735, we find as the length

of the year from Mayan data, 365.2415 mean solar days with an uncertainty of ±0.00025 mean solar days if the long interval is uncertain by ±1 day. This may be compared with 365.2421 mean solar days, the length of the tropical year given for 1900 in the *American Ephemeris and Nautical Almanac* (1950). It may be noted that the Mayan value of the tropical year does not depend in any way upon the correlation of the Mayan and Christian calendar.

However, if a long interval between two Mayan dates turns out to be an integral number of tropical years and a half, the two dates may likely represent a vernal and an autumnal equinox, or a summer and a winter solstice, since these phenomena would have been easily observable by ancient astronomers. In a recent note (Smiley 1960), I have presented a new correlation of the Mayan and Christian calendars which was based on just three assumptions: (a) that the Mayan date, 9–9–9–16–0, 1 Ahau 18 Kayab, represents a date on which Venus was within four days of an inferior conjunction with the sun, and that it was also the date of a solar eclipse visible from Central America, (b) that the interval from this date to 9–14–2–6–0, 1 Ahau 18 Uo, namely 33,280 days, is an interval between two solar eclipse syzygies, as well as the interval between two important Venus dates, namely from a first appearance of Venus as a morning star to a disappearance, somewhat later, as an evening star, and (c) that the earlier correlations of H. J. Spinden (1913), $A = 489{,}384$, and M. W. Makemson (1957), $A = 489{,}138$ were within about a hundred years of the truth. The third assumption was based on early radio-carbon results.

Only two correlations were found which fitted these three assumptions, $A = 482{,}699$ and $A = 500{,}210$. The first of these was chosen for a number of reasons which will be presented in the following paragraphs. By it, the zero date of the Mayan calendar was a solstice date, 3391 B.C., June 26, Gregorian calendar, and the date, 9–9–9–16–0 was another solstice date, A.D. 344, December 22, also Gregorian. Dates before the Christian era are given in this article in the astronomical style in which a year zero lies between 1 B.C. and A.D. 1. By the same correlation, the interval between 9–9–9–16–0 and December 21, A.D. 1960, G.C., was 590,231 days or 1616 tropical years of 365.2420 mean solar days. By the second correlation of this paragraph, the two Mayan dates would correspond neither to equinoxes nor to solstices; this would seem to be reason enough to put that correlation to one side for now.

By the new correlation being retained, $A = 482{,}699$, the initial and final dates of the lunar table in the Dresden Codex (pages 51–58), 9–16–4–10–8, 12 Lamat 1 Muan and 9–17–17–14–6, 10 Cimi 14 Yax correspond to A.D. 477, September 23, an autumnal equinox, and

A.D. 510, June 21, a summer solstice; both dates are in the Gregorian calendar and both are near the times of new moons.

One can, without choosing among the various correlations offered to date, determine the synodic period, P, of revolution of the moon from Mayan data. Using the three eclipse intervals contained in the Venus ephemeris of the Dresden Codex, page 24, one finds:

$$\begin{aligned} 1127\ P &= 33280, & P &= 29.5297 \text{ m.s.d.} \\ 405\ P &= 11960 & P &= 29.5309 \text{ m.s.d.} \\ 317\ P &= 9360 & P &= 29.527 \text{ m.s.d.} \end{aligned}$$

These may be compared with $P = 29.5306$ m.s.d. as given in the *American Ephemeris and Nautical Almanac* (1950). The lunar table of the Dresden Codex does not appear to be quite as precise; $405\ P = 11958$, $P = 29.526$ m.s.d., but it appears likely the lunar table was intended to permit the prediction of new moons over short intervals, and in this, they appear to have been surprisingly successful.

The Mayans' use of 584 days as an approximation to the synodic period of Venus, 583.92 by modern tables, is too well known to need to be discussed here. Again this value does not depend in any way on the particular correlation chosen.

As a further point in favour of the correlation, $A = 482{,}699$, it may be pointed out that of the 92 different lunar dates listed by Teeple (1930), 20 fall in the 72-day interval between March 10 and May 20 inclusive. Of these, 8 fall in the 17-day interval, March 10–26; 2 in the 45-day interval, March 27–May 10; and 10 in the 10-day interval, May 11–20. As one might expect in a country in which the Pleiades were used as a marker for religious purposes, few dates were recorded in April and early May, when the Pleiades were behind the sun.

Again in Teeple's list, Mayan lunar ages are given for 84 dates. Only three of these, numbers 10, 85 and 94 require corrections, in the sense Teeple Mayan minus Modern, outside the range, -4.22 to $+1.65$ days. One may ask, "Why not change A by one day and make the distribution of corrections more nearly symmetrical with respect to zero?" The answer is that the correlation is tied to a solar eclipse which was much more precisely timed by the Mayans than an ordinary new moon.

Almost certainly some persons will say that it is for them unbelievable that the Mayans could have been observing astronomical phenomena as long ago as 3391 B.C. Fortunately there are other signs that point to an early origin for Mexican (and Mayan) astronomy. In a paper, "Venus Period in Picture Writings", Eduard Seler (1904) suggested that Colotl, the scorpion, "marked the cardinal point west for the Mexicans".

Quoting further from the same paper:

"Sahagun says that in some regions, the constellation was called the 'wagon'; that the Mexicans called it 'Scorpion' because it had the shape of that animal; and that it bore this name in many parts of the world. This last remark of Father Sahagun seems to indicate that he identified it with Scorpio, of ancient astonomy. This would imply one of the most remarkable coincidences in the nomenclature. I do not consider this supposition admissible, since Scorpio of the ancients was situated far to the south—from 20° to 40° south latitude."

From this it is clear that Seler was not well-informed on the precession of the equinoxes and its effects on the declinations of the constellations. More than three thousand years before the birth of Christ, Scorpio *was* on the celestial equator and rose in the east and set in the west. More will be said on this later. Without doubt, Colotl *was* our Scorpio, and the implication is that the Mayans were observing the skies before 3000 B.C. There will be some who will say that the Mayans computed backwards to find the time when the Pleiades and Scorpio were on the equator, but this implies a mathematical sophistication even more remarkable than the astronomical assiduity otherwise to be inferred.

Seler also wrote, "In Molina, mamalhuaztli is translated 'astillejos (sticks of wood) constelacion'. Sahagun designates the constellation as 'the wands of the sky, which are near the Pleiades, a group of stars in Taurus' (los mastelejos del cielo que andan cerca de las cabrillas que es el signo del toro)." Later he adds, "In any case, mamalhuaztli could only have been a constellation situated somewhere below 20° north latitude, since it rose at a point due east from the Mexicans, denoting for them the cardinal point east." It seems quite certain that mamalhuaztli was the group of stars now known as the Hyades; it is almost as certain that Seler did not understand that only a star on the celestial equator rises in the east point and sets at the west point of the horizon, regardless of the observer's latitude within the tropics.

In the next paragraph, Seler said, "The neighbouring Pleiades which were named by the Mexicans miec, 'heap', or tianquiztli, 'market', could have had the same significance as the mamalhuaztli. The former constellation, lying below 23° north latitude, might also have marked the east for the Mexicans."

Now is the time to ask the question, when were Alcyone of the Pleiades, Aldebaran of the Hyades and Antares of Scorpio on the celestial equator? The answers are 2950 B.C., 2106 B.C., and 3739 B.C. respectively. About 3350 B.C., Alcyone and Antares were both approximately 2°11′ south of the celestial equator. Then the Pleiades and Scorpio would have

been useful markers near the east and west points of the horizon as they rose and set.

This would seem to indicate that the Mayan knowledge of astronomy reached back to about 3391 B.C. This does not imply that they spent all of the years between this date and A.D. 344 in Central America. Rather, the shift from a June solstice as the zero date in the former year to a December solstice in the latter year suggests that there may have been a migration northward across the equator between the two dates. The Incas in Peru used their 'intihuatanas', 'hitching posts for the sun', as the sun approached the June solstice, dropping lower in the northern sky; if they were to move northward, is it not reasonable to suppose that they would have continued to count from the time when the sun reached the lowest point in the sky?

If one conclusion is to be drawn, it is that we must cease to think of the Mayans as ignorant savages; we must regard them instead as an enlightened people who, in the field of astronomy, were centuries ahead of the rest of the world. It is to be hoped that some enthusiastic young astronomer in Pakistan or India will examine again the question as to when astronomy began in their part of the world.

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THE SCIENTIFIC PAPERS OF ANDREW McKELLAR

The biographical sketch of the late Dr. Andrew McKeller published in the August issue of the JOURNAL *indicated the wide interests of this eminent Canadian scientist. It is fitting that a permanent record of the scope of Dr. McKellar's scientific activity should be made by publishing a complete list of the titles of his papers. The following list is in chronological order, beginning with his work as a graduate student in physics at the University of California and ending with the Presidential Address to the Royal Astronomical Society of Canada at Montreal, April 8, 1960. As the record of thirty years of research the list is impressive*—Editors.

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ELEMENTS OF ASTROMECHANICS

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V. Energy Relations in Orbits. Elements of Space Flight

1. *Work, potential and kinetic energy*

Work done by a force along a linear path is defined as the product of force and distance. For a mass of one gram, the work done, dW, is the product of the acceleration $f_r = dV/dt$ and the distance dr; i.e.

$$dW = f_r\,dr = \frac{dV}{dt}\,dr = \frac{dr}{dt}\,dV = V\,dV, \tag{5.1}$$

from which follows

$$W = \int_1^2 V\,dV = \frac{V_2^2}{2} - \frac{V_1^2}{2} = T_2 - T_1: \tag{5.2}$$

i.e., the work done results in an increase in *kinetic energy* T regardless of character of the force or acceleration.

By definition, *work done by a force* results in *decrease* of *potential energy*, or simply *potential* ϕ, i.e.,

$$dW = f_r dr = -d\phi \tag{5.3}$$

and also

$$\phi = -\int f_r dr, \tag{5.4}$$

while the acceleration f_r (force per unit mass), equals the space-derivative or gradient of the (negative) potential

$$f_r = -\frac{d\phi}{dr}. \tag{5.5}$$

Combining (5.1) and (5.3) we have

$$V\,dV + d\phi = 0. \tag{5.6}$$

Hence

$$\frac{V^2}{2} + \phi = \text{constant}, \tag{5.7}$$

or

$$T + \phi = E \tag{5.8}$$

where E is the constant total energy.

Equation (5.8) expresses the constancy of the sum of the kinetic and potential energy for all time, i.e., the law of conservation of energy. The

zero point for V and hence T can be defined but is arbitrary for ϕ.

If the foregoing holds also for non-linear paths, the force field is called *conservative*, i.e., the *work done* does not depend on the choice of *path* and the potential depends only upon the location. Such is the case for a gravitational field. The vectorial gravitational acceleration (force per unit mass) equals the space-derivative or gradient of the (negative) scalar potential.

2. *The two-body gravitational field. Equation of energy*

In a two-body gravitational field, the relative acceleration amounts to

$$f_r = -\frac{\mu}{r^2} \tag{2.8}$$

where

$$\mu = G(M + m). \tag{2.22}$$

The relative acceleration f_r may be considered to hold for the mass m referred to the M, or vice versa. Hence, the potential referred to either M or m, depending on which is preferred as origin or "rest", is

$$\phi = -\int f_r \, dr = -\frac{\mu}{r} + \text{constant}. \tag{5.9}$$

Since only changes in ϕ are of interest, it is convenient to take $\phi = 0$ at $r = \infty$, in which case the constant $= 0$, and

$$\phi = -\frac{\mu}{r}. \tag{5.10}$$

The statement for conservation of energy (5.7) in the field of inertial "strength" μ becomes, therefore,

$$\frac{V^2}{2} - \frac{\mu}{r} = \text{constant}, \tag{5.11}$$

where V is the relative linear velocity of the two bodies.

Since relation (5.11) does not contain the direction of V, it holds for any location, and within any one orbit determined by the gravitational field. In particular, for a circular orbit of radius a_c, (3.27) becomes

$$V_c^2 = \frac{\mu}{a_c}; \tag{5.12}$$

and (5.11) becomes

$$\frac{V_c^2}{2} - \frac{\mu}{a_c} = -\frac{\mu}{2a_c}. \tag{5.13}$$

Any "circular velocity" non-perpendicular to the radius vector results in an elliptical orbit, for which the energy relation (5.11) may be

written as

$$\frac{V^2}{2} - \frac{\mu}{r} = -\frac{\mu}{2a_c}. \tag{5.14}$$

This relation satisfies the "initial" location, $r = a_c$ in the form of (5.13); obviously the right-hand side remains constant and involves the radius of the circular motion resulting when V is perpendicular to r.

To identify the a_c in equation (5.14) with the semi-axis major of the elliptical orbit, we proceed as follows. At perihelion

$$V_P^2 = \frac{\mu}{a}\frac{1+e}{1-e}. \tag{3.32}$$

Substitution in (5.14) yields

$$\frac{\mu(1+e)}{2a(1-e)} - \frac{\mu}{a(1-e)} = -\frac{\mu}{2a} = -\frac{\mu}{2a_c}. \tag{5.15}$$

Or, we also could make use of the fact that the velocity at the end of the minor axis is given by

$$V_b^2 = \frac{\mu}{a} \tag{3.35}$$

from which again, after substitution in (5.14),

$$\frac{\mu}{2a} - \frac{\mu}{a} = -\frac{\mu}{2a} = -\frac{\mu}{2a_c}. \tag{5.16}$$

Hence $$a = a_c$$

and, after substitution in (5.14),

$$\frac{V^2}{2} - \frac{\mu}{r} = -\frac{\mu}{2a}, \tag{5.17}$$

whence $$V^2 = \mu\left(\frac{2}{r} - \frac{1}{a}\right); \tag{3.45}$$

or $$V^2 = G(M+m)\left(\frac{2}{r} - \frac{1}{a}\right). \tag{3.46}$$

Relations (3.45) or (3.46) hold therefore at perihelion and at the ends of the minor axis for any elliptical orbit with semi-axis major a. Clearly, the same relations hold as r varies along the orbit. As V varies, the total energy remains the same—there being no outside force, only the

"internal" gravitational force playing a role. Hence, equations (3.45) and (3.46) hold for any relative elliptic orbit of two bodies.

Formula (3.45) or (3.46) is often called the *equation of energy*; it is also known as the *integral of energy* or the *vis-viva integral*. An earlier derivation of this formula has been given in Chapter III.

3. *Further energy considerations*

By writing the equation of energy (3.45) as

$$\frac{V^2}{2} = \frac{\mu}{r} - \frac{\mu}{2a} \tag{5.18}$$

it is seen that the linear velocity V at any location in an elliptical orbit may be described in terms of a circumscribing circle of radius $2a$ and centre coincident with the gravitational centre of the ellipse. The velocity V at any point in the ellipse will equal the velocity attained in falling along the extended radius vector from the circle ($2a$) to the ellipse (r).

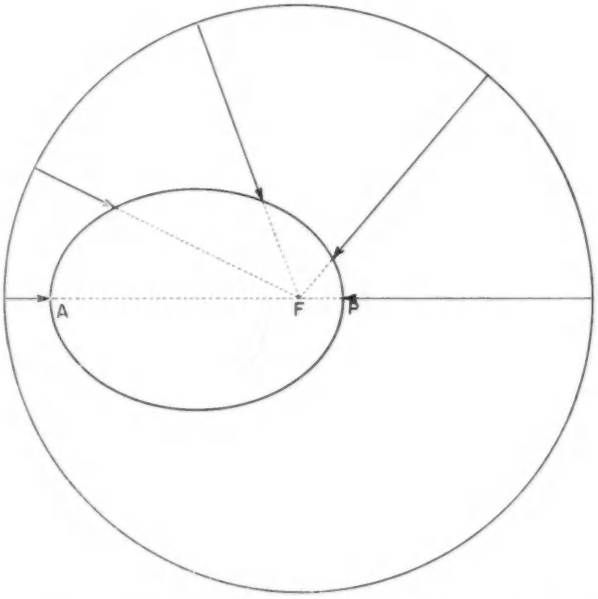


FIG. 5.1—Equation of energy. The velocity in an elliptic orbit of semi-axis major a equals the velocity attained by falling from a circle, concentric with the gravitational centre, with radius $2a$, to the ellipse.

A simple case of the two-body problem is that of a dominant mass M — e.g., the earth and a secondary which, for all practical purposes, has a negligible mass. In this case, we may write (2.8) and (5.10) as

$$f_r = -G\frac{M}{r^2}, \tag{5.19}$$

and

$$\phi = -G\frac{M}{r}; \tag{5.20}$$

while the equation of energy (3.46) becomes

$$V^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right). \tag{5.21}$$

4. *Virial theorem*

For the case of two-body circular motion referred to either mass

$$\text{kinetic energy} \quad T = \frac{V^2}{2} = \frac{\mu}{2r}: \tag{5.22}$$

$$\text{potential energy} \quad \phi = -\frac{\mu}{r}: \tag{5.23}$$

$$\text{total energy} \quad E = -\frac{\mu}{2r}. \tag{5.24}$$

Hence,

$$T = -E, \tag{5.25}$$

$$\phi = 2E. \tag{5.26}$$

This is a special case of the so-called *virial theorem*, a statistical theorem which holds for time-averages of T and ϕ, in a stable system, i.e., a system which does not disintegrate with time. The theorem is named after the quantity $-\phi/2$, which is called the virial of Clausius.

The virial theorem is easily proven for the case of the Keplerian motion when time-averaged over one period.

Since

$$\left(\frac{1}{r}\right)_t = \frac{1}{a} \tag{4.17}$$

we find

$$\bar{T} = \frac{\mu}{2a}, \tag{5.27}$$

$$\bar{\phi} = -\frac{\mu}{a}, \tag{5.28}$$

$$\bar{E} = -\frac{\mu}{2a}, \tag{5.29}$$

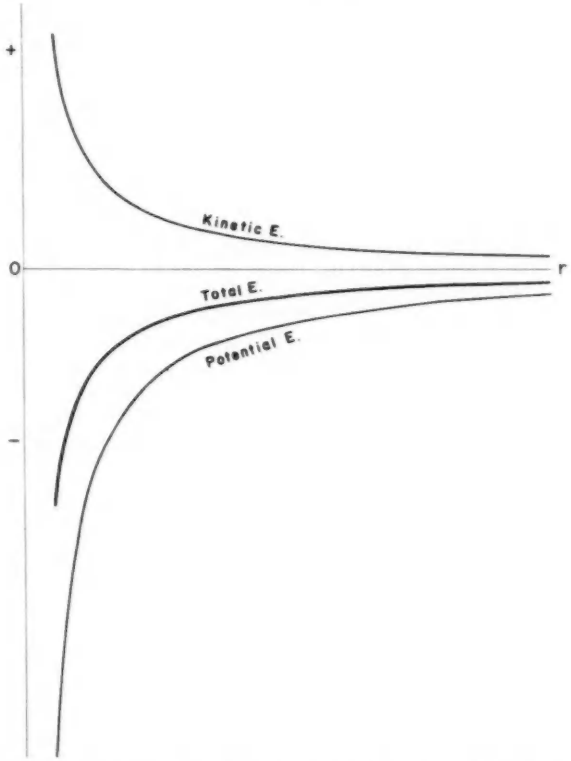


FIG. 5.2—Virial theorem for two bodies. Relation between kinetic, potential and total energy, for circular motion or time-averaged for elliptic motion.

whence

$$\bar{T} = -\bar{E}, \tag{5.30}$$

$$\bar{\phi} = 2\bar{E}. \tag{5.31}$$

5. *Gravitational attraction of sphere having spherical symmetry*

Reference was made in Chapter II to the fact that objects possessing spherical symmetry attract each other as if all their mass were concentrated in their centres. This may be easily shown by making use of the potential concept. The potential, for unit mass at the point P, for a

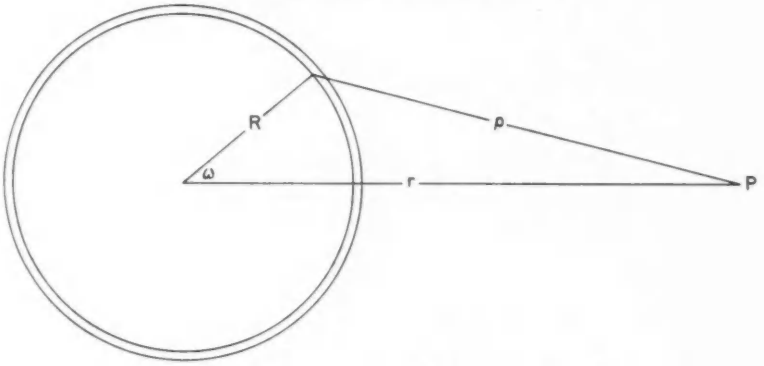


FIG. 5.3—Gravitational attraction of an object possessing spherical symmetry.

gravitational source-element δM is given by

$$\phi = -G\frac{\delta M}{\rho}; \tag{5.32}$$

where ρ is the distance from P to the element δM. For a homogeneous shell of density Δ the potential is

$$\phi = -G\int\frac{\delta M}{\rho}, \tag{5.33}$$

where

$$\delta M = \Delta R^2 dR \sin\omega\, d\omega\, d\theta$$

Here R is the radius of the shell; ω the angle between the radius vector of the space element and the direction of P; θ the angle between the radius vector and a fixed plane through the centre of the spherical shell and the location P. We write

$$\phi = -G\Delta R^2 dR\int_0^{\pi}\int_0^{2\pi}\frac{\sin\omega\, d\omega\, d\theta}{\rho}. \tag{5.35}$$

Let r be the distance from P to the centre of the shell. We can eliminate ρ as follows

$$\rho^2 = r^2 + R^2 - 2rR\cos\omega, \tag{5.36}$$

whence

$$\rho d\rho = rR\sin\omega\, d\omega,$$

or

$$\frac{\sin\omega\, d\omega}{\rho} = \frac{d\rho}{rR}. \tag{5.37}$$

Thus we have

$$\phi_E = -G\Delta \frac{R}{r} dR \int_{r-R}^{r+R} \int_0^{2\pi} d\rho \, d\theta \tag{5.38}$$

if P is outside the shell;

$$\phi_I = -G\Delta \frac{R}{r} dR \int_{R-r}^{R+r} \int_0^{2\pi} d\rho \, d\theta \tag{5.39}$$

if P is inside the shell.
Integrating over ρ and θ, we obtain

$$\phi_E = -G\Delta \frac{R}{r} dR.2R.2\pi = -\frac{G}{r} 4\pi R^2 \Delta dR; \tag{5.40}$$

$$\phi_I = -G\Delta \frac{R}{r} dR.2r.2\pi = -\frac{G}{R} 4\pi R^2 \Delta dR. \tag{5.41}$$

Or, since the total mass dM of the shell of thickness dR is

$$dM = 4\pi R^2 \Delta dR, \tag{5.42}$$

we have

$$\phi_E = -G\frac{dM}{r}, \tag{5.43}$$

$$\phi_I = -G\frac{dM}{R}. \tag{5.44}$$

The corresponding accelerations are the space-derivatives of the negative potential:

$$f_E = -\frac{d\phi_E}{dr} = -G\frac{dM}{r^2}, \tag{5.45}$$

$$f_I = -\frac{d\phi_I}{dr} = 0. \tag{5.46}$$

Integrating over R, i.e. for a sphere of spherical symmetry with total mass M, leads to

$$\text{total } f_E = -G\frac{M}{r^2} \tag{5.47}$$

i.e., the gravitational attraction of a homogeneous sphere acts as if all mass were concentrated in the centre. It follows that the mutual gravitational attraction of two homogeneous spheres acts as if their masses were concentrated in their respective centres.

Formula (5.46) shows that the gravitational attraction of a spherically homogeneous shell on an internal point is zero. This implies that in the

interior of the earth or sun, the gravitational *attraction* results only from matter in the sphere *below*. At the same time the gravitational weight, or *pressure*, of the superimposed layers increases with decreasing distance to the centre.

6. *Elements of space flight; surface potential, velocity of escape*

For a spherical homogeneous object of mass M and radius R, the absolute value g of the surface gravity amounts to

$$g = G\frac{M}{R^2}. \tag{2.26}$$

The amount of the gravitational acceleration f_r above the surface at a distance r from the centre amounts to

$$f_r = -G\frac{M}{r^2} = -g\frac{R^2}{r^2}. \tag{5.48}$$

The energy required to lift one gram vertically against gravity, is equal and opposite to the work W done by the force, i.e.

$$-W = -\int_{r_1}^{r_2} f_r dr = gR^2\int_{r_1}^{r_2}\frac{1}{r^2}dr = gR^2\left(\frac{1}{r_1} - \frac{1}{r_2}\right). \tag{5.49}$$

Hence the energy required to lift one gram from an external point r to ∞ amounts to

$$-W_r^{\infty} = g\frac{R^2}{r}; \tag{5.50}$$

while the energy required to lift one gram from the surface to ∞ amounts to

$$-W_R^{\infty} = gR, \tag{5.51}$$

which is the (negative) *surface potential*. It is equal to the energy required to lift one gram against constant gravity g over a distance R.

The sun's mass and radius are 330,000 and 109.2 times the corresponding values for the earth. For the moon these ratios are 0.0123 and 0.237 respectively. Hence the surface potential of the sun is 330,000/109.2 = 3050 times that of the earth, while for the moon, it is only 0.0123/0.237 = 0.045 times as large.

The term (5.51) is sometimes illustrated as the "depth of the gravitational pit." For the earth, it has a value of 6371 km. For the sun, it is 20,000,000 km. deep; for the moon, it is 280 km. All these quantities are referred to the earth's surface gravity.

To reach infinity, i.e., $a = \infty$, the required parabolic velocity or

velocity of escape V_p follows from the equation of energy (5.21) and is expressed as

$$V_p^2 = 2G\frac{M}{r} \tag{5.52}$$

or, substituting (2.26), $$V_p^2 = 2g\frac{R^2}{r}. \tag{5.53}$$

Hence the velocity of escape varies with the inverse square root of the distance from the centre. In particular, to reach ∞ from the surface the required velocity is expressed by

$$V_p^2 = 2gR. \tag{5.54}$$

To reach a distance r from the surface, i.e., to rise from a distance R to a distance r, the required energy equals the initial kinetic energy, see (5.49), i.e.,

$$\frac{V^2}{2} = gR^2\left(\frac{1}{R} - \frac{1}{r}\right). \tag{5.55}$$

This may be written as

$$r = \frac{2gR^2}{2gR - V^2}. \tag{5.56}$$

The corresponding altitude h above the surface, is given by

$$h = r - R = \frac{2gR^2}{2gR - V^2} - R. \tag{5.57}$$

By writing

$$\frac{V^2}{2} = gR^2\frac{r - R}{rR} = g\frac{R^2h}{Rr} \tag{5.58}$$

we see that, for values of h which are small compared with R and r, formula (5.58) may be written as

$$V^2 = 2gh, \tag{5.59}$$

the well-known formula for low altitudes.

For circular orbits

$$V_c^2 = \frac{\mu}{r} = \frac{GM}{r} = \frac{gR^2}{r}. \tag{5.60}$$

Hence the circular velocity varies, as the velocity of escape does, with the inverse square root of the distance from the centre.

For the sake of completeness, we add the relation for circular velocity near the earth's surface:

$$V_c^2 = \frac{\mu}{R} = \frac{GM}{R} = gR, \tag{5.61}$$

or $$V_c = 7.9 \text{ km/sec. (18,000 m.p.h.)}.$$

Also, the velocity of escape from the earth's surface

$$V_p^2 = \frac{2\mu}{R} = \frac{2GM}{R} = 2gR, \tag{5.62}$$

or $$V_p = 11.2 \text{ km./sec. (25,000 m.p.h.)}.$$

Note that the velocity of escape from the surface of a sphere with spherical symmetry, and likewise the circular velocity at the surface, is proportional to the square root of the (negative) surface potential and therefore proportional to the square root of the quantity M/R. For the solar surface, therefore, the velocity of escape is $\sqrt{3050} = 55$ times that of the earth's surface i.e., 620 km./sec. (1,400,000 m.p.h.); for the moon's surface it is $\sqrt{.045} = 0.21$ times as large or 2.4 km./sec. (5,400 m.p.h.).

For a circular orbit, the period is obtained from

$$P = \frac{2\pi r}{V_c}; \tag{5.63}$$

or, substituting (5.60) it is found that

$$P^2 = \frac{4\pi^2 r^3}{gR^2} \tag{5.64}$$

another version of Kepler's third law.

The period of a circular orbit skimming the earth's surface is thus found to be 90 minutes. For an object circling the earth in 24 hours, the orbital radius is found to be 42,000 km. (26,000 miles).

7. *Time and velocity required to reach the moon*

To just reach the moon from the earth a highly elliptical orbit, with its major axis connecting the orbits of the two bodies may be used. The semi-axis major α of this orbit is very closely one-half of the semi-axis major a of the moon's orbit. Since both orbits are essentially determined by the earth's gravitational field, the harmonic relation between the space and time dimension of these two orbits implies approximately

$$\frac{\alpha^3}{a^3} = \frac{x^2}{P^2}, \tag{5.65}$$

where $P(=27.32$ days) is the period of the moon's orbit and x that of the artificial space vehicle.

Hence, since $\alpha = a/2$, we have

$$x^2 = \frac{P^2}{8} :$$

whence,

$$x = \frac{P}{2\sqrt{2}} = 9.65 \text{ days.}$$

The period of this orbit is 9.65 days; the time needed to reach the moon is one half of this, i.e., approximately 4.82 days or 116 hours.

Take, for example, an orbit whose eccentricity is 0.97. Since the radius of the spherically assumed earth is 0.015 times that of the circularly assumed orbit of the moon, perigee would be near the earth's surface.

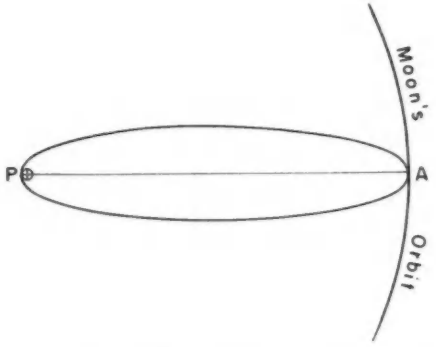


FIG. 5.4—Orbit for reaching moon's orbit.

The semi-axis major of the elliptic orbit would be very close to $1/(1 - e)$ times the radius of the earth, i.e.,

$$\alpha = \frac{R}{1 - e} . \tag{5.66}$$

The velocity at perigee follows from

$$V_P^2 = \frac{\mu}{\alpha} \frac{1 + e}{1 - e} , \tag{3.32}$$

which may be now written as

$$V_P^2 = \frac{\mu}{R}(1 + e). \tag{5.67}$$

For $e = 0.97$ we find

$$V_P^2 = 1.97\,\frac{\mu}{r},$$

while the velocity of escape is given by

$$V_p^2 = 2\,\frac{\mu}{r}. \tag{3.47}$$

Hence, for this particular orbit, the perigee velocity is $\sqrt{1.97/2} = 0.992$ times the velocity of escape, i.e., 11.1 km./sec. (24,800 m.p.h.).

8. *The simple space rocket; mass-ratio*

The characteristics of the orbit of a rocket are the result of its initial location and velocity. The latter is obtained by reaction from the loss of mass (fuel) ejected at high (exhaust) velocity.

Consider a rocket with initial mass m_0, final mass (pay load) m_t and "fuel" $= m_0 - m_t$. For simplicity's sake, let us assume constant exhaust velocity or jet speed v and let V be the velocity of the rocket obtained after all its fuel has been ejected. At any moment the instantaneous forward quantity of motion, or thrust of the rocket, is equal and opposite to the exhaust thrust of the fuel, i.e.,

$$m\frac{dV}{dt} = -v\frac{dm}{dt}, \tag{5.68}$$

or

$$dV = -v\frac{dm}{m}. \tag{5.69}$$

Starting from a position of rest, and in the absence of an external (gravitational) field:

$$V = -v\int_0^t \frac{dm}{m} = v\log_e\frac{m_0}{m_t} = v\log_e R; \tag{5.70}$$

whence

$$R = e^{V/v} \tag{5.71}$$

where

$$R = \frac{m_0}{m_t} \tag{5.72}$$

is the *mass-ratio* of the rocket.

For $R = e = 2.718$, V equals v. To obtain a final velocity of double the exhaust velocity, $V = 2v$, a mass-ratio $R = e^2 = 7.4$ is required; to obtain $V = 3v$, $R = e^3 = 20$, i.e., a mass ratio of 20, or some 95% fuel is required, resulting in a payload of only 5%.

To escape from the earth's gravitational field additional energy is required. Let us assume that a vertical velocity V is built up after t seconds at a constant acceleration ng, hence $V = ngt$. To counteract an assumed constant gravity deceleration of g, the exhaust velocity v has to build up an acceleration $(n + 1)g$, i.e., a terminal velocity $(n + 1)gt$, or

$$V\frac{n+1}{n}. \tag{5.73}$$

The resulting mass-ratio R_n is found from the relation

$$V\frac{n+1}{n} = v \log_e R_n. \tag{5.74}$$

Hence

$$R_n = e^{\frac{V}{v}\frac{n+1}{n}} \tag{5.75}$$

or

$$R_n = R^{\frac{n+1}{n}} \tag{5.76}$$

Clearly very high mass-ratios are required for low values of n, implying slow accelerations, and for low exhaust velocities v. For the extreme case, where $n = 0$, the rocket simply "sits on its exhaust" and gets nowhere while consuming the rocket's fuel. To be practical, we must aim for high exhaust velocities and high accelerations, i.e., a fast rate of using fuel.

For further study, consult "Interplanetary Flight, An Introduction to Astronautics" by Arthur C. Clarke; published by Harper and Brothers.

(*To be concluded*)

SAMUEL ALFRED MITCHELL, 1874–1960

By A. Vibert Douglas
Queen's University, Kingston, Ontario

The name of S. A. Mitchell is among the well known names of American Astronomers of this century. Born in Canada at Kingston, Ontario, in 1874, he matriculated from the Kingston Collegiate, the school to which Sir John A. Macdonald had gone in much earlier years. At Queen's University, Mitchell came under the influence of "one of the finest teachers I have ever known", Nathan F. Dupuis, Professor of Mathematics. He was attracted also to the course in astronomy given by an enthusiastic aged professor, Rev. Dr. Williamson, who had held various positions on the Queen's Faculty since its foundation in 1841.

Graduating in 1894 with the gold medal in mathematics, Mitchell was a junior instructor for a year in both mathematics and physics and then went to Johns Hopkins University, where he specialized in astronomy and received his Ph.D. in 1898 with a thesis on the application of the concave grating to stellar work. Practical work at Yerkes Observatory and a professorship at Columbia University filled the next fourteen years.

In 1912 the Directorship of Leander McCormick Observatory in Virginia was offered him and this post he held until his retirement as Director Emeritus in 1945. For twenty-one years he retained his Canadian citizenship and then in 1933 he became a naturalized American. After retirement he continued to live in Virginia until a few years after the death of his wife when he went to his son's home in Bloomington, Indiana. A severe illness ended in his death on February 22, 1960 at the age of 86 years.

The scientific lifework of S. A. Mitchell falls into two parts, the most important being the determination of 260 stellar parallaxes (published in 1920) and of 440 parallaxes (1927) by the photographic method which had recently been introduced. In 1927 also he collaborated with C. G. Abbot to produce a text-book *Fundamentals of Astronomy*. In 1935 he produced two papers on long-period variable stars.

The more spectacular side of his work resulted from his zest for observing eclipses of the sun. He liked to boast of his record of ten total eclipses, for seven of which he was blessed with good weather; a rather peculiar boast which seemed to give him much pleasure was that every bit of his eclipse equipment on every occasion was borrowed from other observatories, none of it belonging to the observatory of which he was a

director. These expeditions took him to four sites in the U.S.A., to Magog in Quebec, to Sumatra, Norway, Tin-can Island, Canton Island and Spain. The lasting results are found in three publications giving the spectrum of the chromosphere (1930) and from the flash spectrum the heights in the chromosphere at which the atoms of various elements radiate (1930) and the spectrum of the corona (1932). His very personal and popular account of these expeditions *Eclipses of the Sun* 1923 was expanded from time to time until a 5th edition appeared in 1951.

The work of Mitchell and his associates—to whom he owed more than he realized—led to his membership in the International Astronomical Union in the Commissions on Stellar Parallaxes (where he succeeded Schlesinger as chairman in 1928), and the Commissions on Variable Stars, Solar Physics and Solar Eclipses (chairman 1935–50). He was awarded the Watson·Gold Medal of the U.S. National Academy of Sciences, was elected an Associate of the R.A.S. and in 1957 an Honorary Member of the R.A.S.C. For "meritorious contributions to the honour" of his alma mater, Dr. S. A. Mitchell received the Montreal Alumni Medal in 1959. He was a happy man, never happier than when recounting his exploits as the champion eclipse hunter of his day.

METEOR NEWS

By Peter M. Millman

National Research Council, Ottawa, Ontario

THE BRUDERHEIM METEORITE

Following the publication of a catalogue of Canadian meteorites in Meteor News some years ago (JOURNAL, vol. 47, pp. 29, 92, 162; 1953) several additional objects found in Canada have been under investigation as suspected meteorites, but final conclusions concerning their nature have not yet been reached.

However, at 1:06 a.m. M.S.T. early Friday morning, March 4, 1960, a very brilliant fireball passed over southern Alberta, and this resulted in a shower of stony meteorites which were scattered over an area several miles across just north of Bruderheim, Alta. The centre of the area from which meteorites were collected is at latitude 53°54′ N, longitude 112°53′ W. The distribution of the stones was reminiscent of previous meteorite showers, such as the Homestead, Iowa, of 1875 or the Holbrook, Arizona, of 1912. The largest stones were all found at the eastern side of the fall area, indicating a general direction of fall from the west.

The Edmonton Centre of the Society, headed by Earl Milton of the meteor observation group, was active in the early stages of organizing the collection activity for this fall. Later, Professor R. E. Folinsbee, Head of the Department of Geology of the University of Alberta, Edmonton, took charge. The University has collected as many as possible of the Bruderheim stones, including most of the large members of this fall, and has made records of other specimens found, in an attempt to provide as complete a tally as possible of all the stones recovered. At last report somewhat over 500 lb. weight of stone meteorites had been weighed in. These ranged all the way from the 5 largest members, between 50 and 70 lb. each, down to small but completely encrusted fragments less than a fifth of an inch in diameter.

On a recent visit to Edmonton I was enabled to examine the Bruderheim stones, through the courtesy of the Department of Geology of the University of Alberta. I was impressed with the complete and well preserved character of the black fusion crust that covered the great majority of the specimens.

Professor Folinsbee and his staff are planning a detailed study of the circumstances of this meteorite fall, the largest of all Canadian meteorites whether find or fall. We will look forward with interest to hearing more about the Bruderheim in the future. It is fortunate that it occurred close to a centre of population so that the recovery of the meteorites and the scientific study of the phenomenon are assured.

The Associate Committee on Meteorites

The National Research Council has recently appointed a new committee. The Associate Committee on Meteorites has been formed to provide a co-ordinating body which can deal, on a national basis, with matters concerning the recovery and study of Canadian meteorites. The chairman of this committee is Dr. S. C. Robinson, Geological Survey, Department of Mines and Technical Surveys, Ottawa; the secretary is Dr. B. A. McIntosh, National Research Council, Ottawa. The committee includes representatives from both university staffs and government departments.

Dr. Frederick Charles Leonard

With deep regret the death of Professor F. C. Leonard is noted in these pages. Dr. Leonard had for many years been interested in the science of meteoritics. From 1922 until his death Dr. Leonard was in the Department of Astronomy, University of California at Los Angeles, and during this interval he served as chairman of the Department for many years. Dr. Leonard held membership in many learned societies. He was Past-President and Editor of the Meteoritical Society and a Life Member of the R.A.S.C. He will be greatly missed by his many astronomical friends and associates.

VARIABLE STAR NOTES

By Margaret W. Mayall

The American Association of Variable Star Observers, Cambridge, Mass.

The 1959 Spring Meeting of the A.A.V.S.O. was held in a big city—Chicago, and the Spring 1960 Meeting in a still larger one—New York. The Amateur Astronomers Association and the Hayden Planetarium, through the director, Mr. Joseph Chamberlain, were our hosts. Once again, a planetarium building was our headquarters, and all of their fine facilities were made available to us.

The Hayden Planetarium has recently completed the installation of a new Zeiss projector. The many new features and improvements were ably demonstrated at a special session by one of our own members on the staff of the Planetarium, Mr. James Pickering, son of the late David Pickering, of A.A.V.S.O. fame. We watched a nova suddenly rise to first magnitude, and several variable stars go through their phases, in addition to demonstrations of other heavenly phenomena. It was good to see that the new Zeiss projector shows bright stars as brighter images, and not larger disks as some of the older ones did.

A list of 36 applications for membership in the A.A.V.S.O. was presented to the Council. The following were elected to Annual membership: Lynwood G. Aubrecht, *Illinois*; Hector Ayala R., *Mexico*; Keith Axelson, *California*; Thomas Borlik, *Indiana*; Donald A. Bradley, *New York*; Tom C. Constanten, *Nevada*; Robert B. Covell, *New York*; Jon Dahlquist, *New York*; Daniel Della Pietra, *New York*; Roberto O. Dessommes, *Mexico*; Russell C. Feurst, *California*; Bland J. Fulghum, *Mississippi*; Roger P. Gaver, Jr., *Maryland*; Art. Gonthier, *Mexico*; R. Lansing Hicks, *Connecticut*; Jerome A. Hudson, *Texas*; Tim Hunter, *Illinois*; Junior Astronomy Club, *New York*; Joseph R. Kammel, *New York*; Craig R. Kennedy, *Iowa*; Lakehead Astronomical Society, *Canada*; Michael Leibowitz, *New York*; Dan Leithoff, *Oregon*; Joel S. Levine, *New York*; Mrs. James Lucas, *Ohio*; John S. Lynch, *Texas*; James D. McCarthy, *Cuba*; Mount Si High School Mathematics Club, *Washington*; Mrs. John T. Newton, *California*; Daniel A. Poole, Jr., *California*; William S. Quigley, *Ohio*; Stephen L. Sala, *California*; D. A. Sherwood, *Canada*; Leo V. Standeford, *Illinois*; Stephen Ungar, *New York*; Van A. Wilson, *Arizona*.

The announcement of future meetings of the A.A.V.S.O. includes the 1960 Annual Meeting in Springfield, Massachusetts, in the middle of October and a Spring meeting in Ottawa, May 26–28, 1961. The Council will be glad to receive definite invitations and suggestions for other meetings. The one restriction in our Constitution is that the Annual Business meeting must be held in Massachusetts in October.

The A.A.V.S.O. publishes Abstracts of papers given at the meetings, so a full report will not be given here. As usual, many subjects were covered during the session for

papers. It started with *Random Comments of an Amateur Astronomer* by William Cleaver, who put into words the thoughts and feelings of all good observers. The October 1959 eclipse of the sun produced two papers: *Visual Observations of Moon's Shadow*, William Glenn, and *Photometric Observations of Sky Brightness*, Victor Gogolak. Albert Ullmann showed some slides of the beautiful Palomar colour photographs of nebulae, *Heavenly Hues*. Kenneth Weitzenhoffer talked on *The Radio Telescope Simplified*.

Discussions of solar problems included a paper by Ralph N. Buckstaff, *A Solar Flare*, which may have been an observation of the rare "white flare", and a discussion by Harry L. Bondy of *White Flares*. Mr. Bondy also gave a report from the A.A.V.S.O. Solar Division on the work involved in obtaining American Sun-spot Numbers and the recording of Sudden Enhancements of Atmospherics.

Variable stars and novae were covered in the following papers: Patrick Rizzo, *A Check List for Locating Variable Stars*; Florence Glenn, *The Inside Story of a Nova*; and Margaret Mayall, *The Light Curve of R Coronae Borealis*, and *Nova Herculis 1960 —A Comedy of Errors*, listing many of the errors which crept into the various announcements and charts of the Nova and its comparison stars.

Richard Hamilton spoke about *The Stamford Observatory* and showed slides and plans of the new observatory being constructed at the Stamford Museum's Nature Center, in Connecticut. Edward Oravec gave excerpts from the *Annual Report of the Chairman of the Observing Group of the Amateur Astronomers Association*. The activities of their group are reminiscent of the work of the Montreal Centre of the R.A.S.C.

The New York meeting closed with a memorable roast beef dinner in Mayor's Hungarian restaurant. Members were pleasantly surprised when it was announced that door prizes were to be given, and even more surprised when it was discovered that among them were several very lovely pieces of jewelry set with diamonds and pearls.

The long holiday week-end of May 27–30 enabled many members to enjoy some New York sightseeing, shopping and theatre going. Our hosts did everything possible to make the stay a very pleasant one.

185213 Nova Herculis 1960. All indications are that Nova Herculis should be one of the best observed novae on record, thanks to Mr. Hassel's discovery of it in the morning twilight sky. It is in an excellent observing position throughout the summer and early fall.

The light curve on page 252 shows a very slow steady decrease in brightness, following the first rapid drop of about 2 magnitudes in a few days. The curve had a very close resemblance to the curve of RS Ophiuchi, a recurrent nova, during the first month of observation, and later observations continue to follow the same pattern.

Dr. McLaughlin of the University of Michigan found the rare red coronal line at 6374 A. wave-length during his spectroscopic studies of Nova Herculis 1960. The coronal lines have been detected in the spectra of most of the recurrent novae, and in four normal novae, but in no other stellar source outside the solar corona. The line λ6374 is due to highly ionized iron, and occurs only at extremely high temperatures and low pressure. On May 19th (J.D. 2437074) it was much stronger than it was ever before observed.

Only the years will reveal if Nova Herculis 1960 is a recurrent nova similar to RS Ophiuchi.

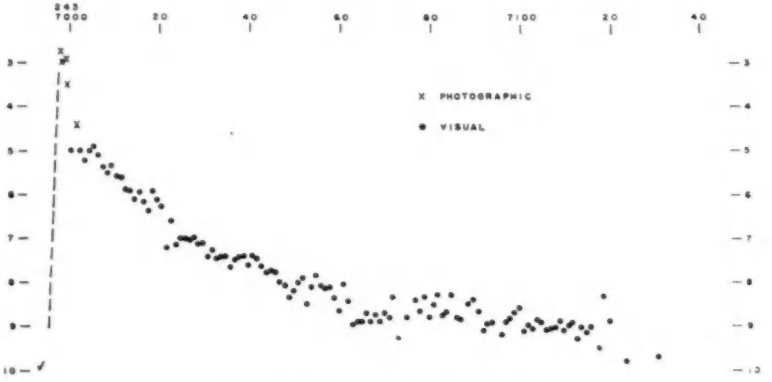
Milestones. A very important milestone in A.A.V.S.O. history was passed on June 27 when Cyrus Fernald made his 100,000th variable star observation. Just 2 years before, on June 22, 1958, Reginald de Kock made his 100,000th observation. The total number of A.A.V.S.O. observations is well on its way toward the 2,000,000 mark. If observations continue to be made at the same rate, the big mark should be reached in a few years.

Observations received during May and June 1960. A total of 11,312 observations was received: 7,449 from 91 observers in May, and 3,863 from 87 observers in June.

Observer	May Var.	May Ests.	June Var.	June Ests.	Observer	May Var.	May Ests.	June Var.	June Ests.
Adams, R. M.	86	150	82	161	Lacchini, G. B.	16	67	21	52
Anderson, Carl	..	..	4	8	Langenbeck, U.	3	14	..	..
Anderson, Curtis	41	51	46	51	Lattey, M.	8	12	10	26
Axelson, K.	4	8	2	6	Lehmann, P. B.	1	7	..	..
Ayala R., H.	1	4	5	18	Lowder, W. M.	..	..	18	22
Balassa, T.	6	10	..	..	Lynch, J. S.	..	..	1	2
Ball, A. R.	..	..	17	23	Mannuccia, A.	..	..	1	15
Barrera, S.	7	8	..	..	Martinez G., A. E.	3	196	..	..
Barroso, J. J.	13	21	12	33	Matthies, D.	..	..	1	1
Berg, J.	48	91	26	42	McPherson, C. A.	12	12	11	11
Berg, R.	25	25	..	..	McWilliams, A.	..	..	2	7
Bicknell, R. H.	..	..	16	12	Mende, R.	3	20	1	12
Brady, R. F.	24	45	14	14	Miller, Robert	14	14	21	25
Braune, W.	32	186	28	56	Miller, William	4	4	12	19
Brechlin, D.	..	..	2	2	Montague, A. C.	12	17	17	26
Buckstaff, R. N.	..	..	25	83	Morgan, F. P.	15	28	5	11
Buckley, A. K.	..	..	1	1	Mourao, R. deF.	5	6	2	2
Carbacho, P.	1	1	..	..	Mourilhe S., P.	10	21	13	35
Carlisle, J. H.	4	6	..	..	Muniz B., L.	12	27	12	24
Celis S., L.	14	111	..	..	Nightingale, H. C.	4	8	7	19
Cragg, T. A.	170	181	190	214	Olmsted, M.	8	21	7	12
Crotty, J.	..	..	3	3	Oravec, E. G.	150	309	107	167
Darsenius, G.	1	2	..	..	Orchiston, D. W.	57	345	68	416
Dawson, B. H.	35	68	..	..	Ormazabal, M. E.	1	1	..	..
Debono, I. P.	11	16	13	26	Pearcy, R. E.	2	2	1	1
de Kock, R. P.	115	571	121	503	Peltier, L. C.	26	169	16	37
de la Vega, R.	58	2702	..	..	Peters, P.	8	8	..	..
Diedrich, DeL.	..	..	3	3	Price, R. T.	21	27	13	19
Diedrich, G.	3	5	4	8	Quester, W.	8	30	9	18
Dudley, R. R.	12	12	..	..	Quigley, S.	3	5	..	..
Ellerbe, J. E.	..	..	3	5	Renner, C. J.	46	46	..	..
*Engelkemeir, D.	10	18	8	15	Ries, J.	..	..	8	8
Estremadoyro, G. A.	12	12	..	..	Rizzo, P. V.	10	20	14	21
Estremadoyro, V. A.	2	2	..	..	Robinson, L. J.	49	110	2	5
Farmer, R.	..	..	6	6	Rosebrugh, D. W.	7	18	11	34
Fernald, C. F.	154	303	162	222	Sealy, R. N.	2	2	..	..
Ford, C. B.	43	47	99	102	Segers, C. L.	35	121	33	96
Frogel, J. A.	3	4	..	..	Severin, M. A.	14	39	11	39
Fuller, K.	44	50	52	59	Sharpless, A. P.	14	14	13	13
Garland, G.	5	13	..	..	Shinkfield, R. C.	24	69	15	33
Giffen, C. H.	9	35	..	..	Smith, G. W.	..	..	7	7
Glenn, F. R.	1	8	1	6	Solar, E.	5	19	..	..
Glenn, W. H.	1	8	1	6	Stanton, R.	23	23	9	9
Godfrey, N. B.	33	33	..	..	Taboada, D.	26	26	..	..
Goodsell, J. G.	1	1	..	..	Tavares, O. C.	..	..	4	4
Grossenbacher, R. W.	23	25	..	..	Templeton, J. H.	3	3	4	4
Halbach, E. A.	..	..	9	11	Teran, M.	9	56	..	..
Hartmann, F.	99	106	109	120	Tompkins, R.	2	5	2	3
Hicks, R. L.	..	..	4	31	Topp, G.	..	..	3	6
Hiett, L.	3	8	..	..	Traynor, F.	10	16	16	34
Hull, A.	3	3	..	..	van Zyl, L. L.	23	77	21	63
Humphrey, D. R.	5	6	5	5	Vodrazka, G.	..	..	6	8
Hutchings, N. O.	..	..	8	10	Wend, R. E.	..	..	3	3
Judd, D.	4	4	13	13	Wilford, F.	..	..	3	3

Observer	May Var.	May Ests.	June Var.	June Ests.	Observer	May Var.	May Ests.	June Var.	June Ests.
Kaminski, W. J.	..	..	12	12	Williamson, L. J.	3	3	3	8
†Kelly, F. J.	20	26	15	20	Williamson, P. L.	4	15	11	53
Kindt, O. H.	..	..	4	6	Wilson, C. F.	101	180	138	247
Knowles, J. H.	7	8	9	11	Wilson, V. A.	10	35	9	18
Kopp, R.	11	26	13	41	Yamada, T.	48	162	39	84

*Plus 3^h33^m AD Leo PEP †10^m AE Aqr



Light curve of 185213 Nova Herculis 1960.

A.A.V.S.O. Nova Search Report (from George Diedrich, Chairman): Observations of Nova Search areas were made by the following 28 observers for a total of 631 area-nights reported. Each name is followed by the number of observations made in March, and then April, 1960: R. Bishop—1, 0; Mrs. E. E. Bridgen—16, 15; I. P. Debono—1, 3; F. J. DeKinder—11, 9; D. Diedrich—9, 7; G. Diedrich—13, 11; P. Evans—0, 29; K. Fuller—32, 2; G. Gaherty, Jr.—5, 12; D. Humphrey—41, 27; W. Isherwood, Jr.—21, 23; W. Kaminski—0, 1; M. Knuszka—0, 13; J. Low—2, 6; D. Matthies—5, 4; H. Nightingale—12, 12; D. W. Orchiston—42, 47; C. J. Phillips—47, 0; R. Price—0, 10; G. W. Smith—8, 0; F. Traynor—12, 21; G. Vodrazka—0, 7; R. Walk—7, 0; W. A. Warren—8, 0; G. Wedge—6, 10; K. Westbrook—17, 16; I. K. Williamson—9, 5; K. Zorgo—8, 8.

NOTES FROM OBSERVATORIES

Dominion Astrophysical Observatory, Victoria, B.C.

The Observatory suffered a very serious loss in the death of Dr. Andrew McKellar on May 6. In addition to being Assistant Director, he was one of Canada's foremost astronomers and had made an international reputation in the study of molecules in the stars and comets and atmospheres of the cool stars. See p. 153 of the August issue. Mr. J. D. Francis, who had been on the staff as a summer assistant from 1956 to 1958 and as a permanent member since 1958, lost his life in a canoeing accident on the Cowichan River on April 18.

Dr. Jean K. McDonald resigned from the staff and was married to the Director, Dr. R. M. Petrie, on April 9. She is to continue her astronomical career as a lecturer in astronomy at Victoria College in the Fall. Miss Anne K. Lucas resigned to be married on June 11. Dr. Alan H. Batten, N.R.C. Postdoctorate Fellow was married on July 30 and Mr. Donald H. Andrews was married on August 13.

Mr. E. K. Lee, Mr. W. H. R. White, and Mr. Bernard Caner returned from educational leave. Mr. Donald H. Auld joined the Geomagnetic Division on May 24 and Miss Sandra Meidler joined the Seismological Division on June 6. Dr. Y. Fujita arrived on May 6 from Tokyo University to spend some months under an I.A.U. grant, studying spectra of the carbon stars. The following seasonal appointments have been made: R. L. Hemmings (Seismology), R. A. Lawson, F.C.J.T. Loehde, S. C. Morris, A. J. Perry-Whittingham (Geomagnetism) and K. J. Rooney.

Dr. and Mrs. Petrie attended the following meetings: the Astronomical Society of the Pacific in Eugene, June 13–14 where Dr. Petrie took part in a symposium on "The Distance Scale of the Galaxy"; the opening ceremonies for the Dominion Radio Astrophysical Observatory in Penticton June 20–22; the I.A.U. Executive Committee in Prague July 6–8; and the annual Liège Symposium on the "Far Ultraviolet Spectra of Astronomical Bodies" July 11–13. They visited the Grubb-Parsons Works to observe the progress on the new 48-inch telescope that is to be delivered in the spring of 1961. K. O. Wright and G. J. Odgers also attended the Symposium on Radio Astronomy at Penticton.

Dr. Anne B. Underhill attended the Fourth Symposium on Cosmical Gas Dynamics in Varenna, Italy in August and presented an invited paper on "Astronomical Turbulence".

REVIEW OF PUBLICATIONS

Introduction to the Mechanics of the Solar System by Rudolf Kurth. Pages ix+177; 5½×8½ in. New York, Pergamon Press, 1959. Price $6.50.

This is the second text-book issued recently by Pergamon for a first course in celestial mechanics, probably in response to interest in the subject stimulated by Sputnik. Based on a Manchester lecture course, its four chapters treat the kinematics and dynamics of a single planet, dynamics of the solar system including first-order perturbations and finally the effects of flattening on the motions of the earth and moon. Exercises and notes with brief bibliographies follow each chapter.

Grasp of fundamental principles is aimed at, rather than quantitatively exact results. To this end direct methods are used leading to approximte formulae capable in turn of further improvement by similar methods. Enough heed is paid to rigour to chill any who associate this word with *mortis*. Vectors are employed freely; only three diagrams appear. Some hard things are said incidentally about Hamilton-Jacobi theory; authors of recent papers in *The Astronomical Journal* on artificial satellite perturbations appear not to share Kurth's views.

Compared with Moulton's *Celestial Mechanics*, a standard American text-book covering roughly the same ground, Kurth's much shorter book has a more mathematical, less astronomical tone, and is less suited for reference or independent study. However, since one of the difficulties in celestial mechanics is seeing the woods for the trees, the difference in viewpoint should make this book useful as supplementary reading in any introductory course.

R. W. TANNER

Moving Envelopes of Stars by V. V. Sobolev, trans. by Sergei Gaposchkin. Pages 106; 5½ × 8½ in. Toronto, S. J. Reginald Saunders & Co. Ltd., 1960. Price $5.45.

The language barrier being what it is, this translation by Sergei Gaposchkin of Sobolev's monograph on *Moving Envelopes of Stars* fills a definite need.

All astrophysicists will agree that stellar spectra containing emission lines are interesting. Even more interesting are the relationships between motions in the atmosphere and the processes which produce the emission

lines. This monograph is one of the first comprehensive attempts to unravel these relationships.

When reading this book, one should remember that it was written in 1947, probably in nearly complete isolation from contemporary work on the subject. The author has an annoying habit of proclaiming that his treatment of the subject is the only acceptable and true interpretation of the observations. Actually, at nearly the same time, others, for example S. Miyamoto and other Japanese astrophysicists, S. Chandrasekhar, and R. N. Thomas, were independently considering the properties of moving atmospheres and the effect of motions on stellar spectra. Each elucidates some aspect of the problem. Their work is written in English. It is most pleasing therefore to have Sobolev's monograph in the same language.

One word of caution. The translator at times renders the Russian for *nova* literally as "new star". In these days when speculation about newly formed and evolving stars is rife, this trait may lead the unwary along a false mental trail.

ANNE B. UNDERHILL

The Magneto-Ionic Theory and Its Applications to the Ionosphere by J. A. Ratcliffe. Pages 206; $5\frac{1}{2} \times 8\frac{3}{4}$ in. London, Cambridge University Press and Toronto, The Macmillan Company of Canada Limited, 1959. Price $6.75.

The magneto-ionic theory describes the propagation of waves in a partially ionized, electrically neutral, gas in the presence of a dominant magnetic field. Although this theory has remained essentially unchanged since its initial formulation, almost thirty years ago, Mr. Ratcliffe's monograph is the first to be published, dealing exclusively with this subject. Its appearance is opportune, for while the theory was first developed to explain the propagation of radio waves in the terrestrial ionosphere, it has recently found application in such diverse fields as astrophysics, radio astronomy, microwave electronics, plasma physics and thermo-nuclear research.

In the first of the book's four sections two approaches are employed in a mathematical development of the theory. The discrete nature of the charges and their individual motions are ignored, in one, and the medium is considered equivalent to a continuous distribution of charge and current. This is termed a macroscopic theory in contrast to the microscopic approach in which the detailed effect of absorption and re-radiation of waves by the individual electrons is considered. The interpretation of the resulting equations is presented in the second section with the aid of physical reasons for the behaviour of the waves

and graphical summaries of the results for convenient application. The second half of the book is devoted to applications of the theory to the terrestrial ionosphere, and a number of related subjects such as inhomogeneous media, mixtures of ions and electrons, and a comparison of crystal optics and the magneto-ionic theory.

Although the book is based on published papers, it includes substantial amounts of unpublished material since the author is considering a field of research to which he has devoted many years, and to which he and his associates have made many important contributions. In addition, the bibliography contains not only the titles of most of the important papers in the field, but also brief summaries of their content. Thus the book is a valuable asset to specialist or student, theorist or experimenter alike.

R. E. BARRINGTON

Philips' Chart of the Stars edited by E. O. Tancock. Folded 6 × 10¼ in., open 46 × 36 in. London, George Philip and Son, Ltd., 1958. Price, paper 6s., cloth with rollers 21s. 6d.

This large sheet shows the stars on equatorial co-ordinates down to fifth magnitude as white disks on a blue background on three maps: the middle part of the sky, within dec. ±55°, across the top of the sheet; the two polar regions, within 52° of the poles, below. The Milky Way and Magellanic Clouds are shown. Tables are included giving, among other things, the first magnitude stars, the chief double and variable stars, clusters and nebulae. These add to the usefulness of the chart.

The star maps have been completely redrawn for this edition and are very clear. Different types of lettering effectively differentiate the names of constellations from those of individual stars or other objects.

Philips' Chart of the Stars is an attractive and useful chart to mount on a wall.

RUTH J. NORTHCOTT

The Indian Ephemeris and Nautical Almanac for the Year 1961. Pages 448; 7¼ × 10 in. Calcutta, Government of India Press, 1960. Price Rs 12.50 nP or 19s 6d.

This Ephemeris is similar to the ephemerides issued by the Nautical Almanac Office, U.S. Naval Observatory and by H. M. Nautical Almanac Office, Royal Greenwich Observatory. This is the fourth year of publication.

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The Society publishes this JOURNAL bi-monthly (February, April, June, August, October and December) and the OBSERVER'S HANDBOOK annually. Single copies of the JOURNAL are 75 cents, of the OBSERVER'S HANDBOOK, one dollar.

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